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Agricultural Memorandum No 1083

Estimating Daily Maximum and Minimum 10 cm Soil Temperatures from Standard Meteorological Data

I A Barrie

Summary

A selection of simple equations have been derived which permit the calculation of daily maximum and minimum 10 cm soil temperatures from commonly available daily recordings of the 0900 GMT 10 cm temperature, daily sunshine hours (or solar radiation) and daily maximum and minimum air temperatures - used separately or in combination. Errors in the subsequent calculation of daily mean soil temperature are normally less than 0.8°C. The variation of the calculations between the months of April, May and June is examined. The influence of soil texture, soil moisture content and aspect cannot be absolutely quantified from the limited amount of data presented, but they are shown to be of secondary importance and do not prevent the application of the relationships.

These equations are well suited to the calculation of accumulated soil temperatures in entomological and crop emergence studies; climatological statistics of 10 cm soil temperature can also be derived.

Introduction

The standard shallow soil temperature recordings at climatological stations are spot readings, once per day at 0900 GMT, at depths of 10 cm and 20 cm below a surface free from any vegetation. These readings are close to the 24 hour minimum during the spring (Gloyne, 1980; Barrie, 1985). This data is not adequate for many studies which require knowledge of the daily maximum and minimum temperatures which largely depends on the energy balance at the soil surface.

Empirical relationships have previously been determined for the daily maximum soil temperature at 5 cm (Cochrane, 1969) and the maximum and minimum daily soil temperatures at 10 cm and 30 cm for a loam soil at Kew (Cochrane and Baker, 1985).

The relationships presented in this memorandum permit a daily calculation of maximum, minimum and hence mean 10 cm soil temperatures given a wide choice of input data.

Results

A study of maximum, minimum and 0900 GMT soil temperatures at depths of 5 cm and 10 cm was initiated by ADAS Entomology, Harpenden in 1983. Six MAFF climatological stations cooperated in this study and the daily values have been archived on the PRIME system at Guildford (Baker, CR. private communication). Extracts from this data-set have been used to develop relationships for the spring and early summer months and so permit, for example, the formulation of an accumulated soil temperature relationship for the date of egg-laying for the overwintered generation of the raspberry cane midge (Resseliella theobaldi (Barnes)) (Gordon and Barrie, 1987).

A.1 Estimating the daily minimum 10 cm soil temperature

Because the minimum soil temperature normally occurs between sunrise and 0900GMT, the minimum can be determined by deducting a constant from the 0900 GMT reading. The monthly mean differeces $T_9 - T_{sn}$ are given in Table 1.

Key for symbols

T_{sx} daily max 10 cm soil temp. (usually occurs in the early afternoon) °C
T_{sn} daily min 10 cm soil temp. (usually occurs just after sunrise) °C
T_9 0900 GMT 10 cm soil temp. °C
R daily total global solar radiation (measured) in $Whrm^{-2}$
Rc daily total global solar radiation (calculated: Cowley) in $Whrm^{-2}$
$(T_x-T_n)_A$ daily range of air temps. (max-min) °C.

Table 1. Daily mean differences between 09GMT and minimum soil temperatures °C

	1985				1986			
	March	April	May	June	March	April	May	June
Luddington	0.9	1.2	1.2	2.0	1.2	1.3	1.9	2.0
Stockbridge	1.0	1.5	1.8	2.4	1.1	1.6	2.5	2.2
Rickwood	0.5	1.0	1.1	1.2	0.7	0.7	1.6	1.4
Boxworth	1.2	-	-	2.0	1.6	2.0	2.7	3.5
Bridgets	0.7	1.4	1.2	1.1	1.3	1.9	1.7	2.4
Terrington	1.1	1.5	1.7	1.3	1.2	1.4	2.2	2.2
Mean	0.9	1.3	1.4	1.7	1.2	1.5	2.1	2.3

Table 1 reflects the increasing differences between T_{sn} and T_9 as the time of sunrise advances through the months from March to June. Averaging between the two years produces the constants:-

March 1.1°; April 1.4°; May 1.7°C and June 2.0°C. The differences between stations are most likely to be due to soil moisture and the texture of the topsoil (see Annex 1). Arthur Rickwood Farm, for example, has a deep peat soil with a very high thermal capacity.

B.1 Estimating the daily maximum 10 cm soil temperature

Four methods are presented which involve using different parameters in a simple surface heat budget approach. None of them require as inputs details of soil moisture content or soil texture class (ie thermal conductivity) although it can be seen in Table 2 that there are differences of up to 3°C between sites, some of which will be accounted for by greater solar radiation levels at the more southerly sites. The influence of soil texture, soil moisture and aspect is reviewed by Rosenberg (1983) and the incorporation of these variables into the regression offers scope for additional refinements. However, an empirical scheme, which fits relevant biological observation, is presented later.

Table 2. Daily mean differences between maximum and 0900 GMT soil temperatures

	1985				1986			
	March	April	May	June	March	April	May	June
Luddington	1.9	1.8	1.8	2.7	2.0	2.6	2.5	3.2
Stockbridge	2.9	3.0	3.5	3.4	2.5	2.7	2.9	3.9
Rickwood	1.6	2.3	2.4	2.6	1.5	2.1	2.6	3.7
Boxworth	2.5	-	-	4.0	3.0	3.1	3.8	4.5
Bridgets	2.6	3.4	4.0	3.8	2.8	4.0	3.9	6.2
Terrington	3.0	2.7	3.0	2.9	2.4	2.6	3.0	4.9

B.1.1 Measured solar radiation

Measurements of daily total global solar radiation were obtained from Luddington and Stockbridge House for the months April to June. The readings are from 0900 to 0900 GMT, not sunrise to sunset, which introduces a level of uncertainty into the analysis. Each month has been analysed separately, with a further regression for the months combined:-

Luddington 1986

		r^2	r	
April	$T_{sx} = T_9 + 0.659 \times 10^{-3} R + 0.632$	.50	.71	(1)
May	$T_{sx} = T_9 + 0.729 \times 10^{-3} R - 0.102$	.45	.67	(2)
June	$T_{sx} = T_9 + 0.813 \times 10^{-3} R - 0.613$	.64	.80	(3)
All	$T_{sx} = T_9 + 0.681 \times 10^{-3} R + 0.238$	.55	.74	(4)

Stockbridge House 1985

		r^2	r	
April	$T_{sx} = T_9 + 0.934 \times 10^{-3} R + 0.079$	.72	.85	(5)
May	$T_{sx} = T_9 + 0.987 \times 10^{-3} R - 0.357$	.79	.89	(6)
June	$T_{sx} = T_9 + 0.842 \times 10^{-3} R - 0.684$	.72	.85	(7)
All	$T_{sx} = T_9 + 0.837 \times 10^{-3} R - 0.017$	.70	.84	(8)

For practical purposes the general equations for the months combined can be used (Eq.4, Eq.8).

B.1.2 Caculated solar radiation

If on-site totals of total global solar radiation are not available then they may be calculated from daily sunshine totals (Cowley, 1978). This method has the advantage of being based on a sunrise to sunset reading but as the calculation of solar radiation itself is not exact, then the net difference over the previous method is small.

The method was tested for Luddington in 1986, giving for April-June.

	r^2	r	
$T_{sx} = T_9 + 0.627 \times 10^{-3} Rc + 0.499$	.50	.71	(9)

This compares with eq.(4) above and gives a slightly poorer correlation coefficient.

B.1.3 Diurnal range in air temperature

The diurnal range in air temperature is closely related to the diurnal variation in shallow soil temperature. The resulting regressions are given for April-June:

Stockbridge 1985

	r^2	r	
$T_{sx} = T9 + 0.416 (T_x - T_n)_A - 0.051$	.57	.75	(10)

Luddington 1986

$$T_{sx} = T_9 + 0.367\ (T_x - T_n)_A - 0.007 \qquad r^2 = .67 \quad r = .82 \qquad (11)$$

These equations are very similar to that derived by Hough (personal communication) for a blowing loamy sand site near Skipworth in 1980:

$$T_{sx} = T_9 + 0.38\ (T_x - T_n)_A - 0.264 \qquad r = 0.85$$

B.1.4 Combined solar radiation and air temperature

The best general relationships involved both daily totals of global radiation (measured or calculated) and maximum and minimum air temperatures; for the April-June period we have:-

Stockbridge 1985

$$T_{sx} = T_9 + 0.153\ (T_x - T_n)_A + 0.626 \times 10^{-3} R - 0.416 \qquad r^2 = .73 \quad r = .85 \qquad (12)$$

Luddington 1986

$$T_{sx} = T_9 + 0.28\ (T_x - T_n)_A + 0.266 \times 10^{-3} Rc - 0.417 \qquad r^2 = .72 \quad r = .85 \qquad (13)$$

Equations 12 and 13 give very similar results over the range of temperature and solar radiation expected in these months.

Discussion

Any particular application of these regressions will have individual restraints. Commonly meteorological data will be limiting although there is a network of over 400 stations in the UK recording air temperatures, 150 of which also record 10 cm soil temperatures.

The crop under study may also be limiting when pests of horticultural crops may be associated with generally light soils which tend to be warmer by day but also cooler by night when compared to heavier soils. Studies of cereals, conversely, will be biased towards those heavier soils. Clearly then a more comprehensive analysis is needed to produce regressions more applicable to cover some specific studies.

The type and extent of crop cover is another variable which has to be considered. In a previous study (Baker, 1981) the difference in dates between the accumulation of soil temperature to 430°C days under several exposures (above a base of 5°C between February and June 1976-78) was found to vary by only two days between bare soil and flat grass covers. In this study aspect had a much greater influence on soil temperature than did crop cover.

Consequently, it may be concluded that for many practical purposes a simple regression may be employed during the spring and early summer months in the calculation of maximum 10 cm soil temperatures. Those recommended below are averaged between the sites chosen for the analysis.

$$T_{sx} = T_9 + 0.391\ (T_x - T_n)_A - 0.029 \qquad \text{(from 10 and 11)*}$$

$$T_{sx} = T_9 + 0.759 \times 10^{-3}\ R + 0.11 \qquad \text{(from 4 and 8)}$$

$$T_{sx} = T_9 + 0.216\ (T_x - T_n)_A + 0.446 \times 10^{-3}\ R - 0.416 \qquad \text{(from 12 and 13)}$$

The choice of regression will depend more on the data and computing power available rather than on one method being noticeably superior to another.

Effect of Aspect, Soil Moisture and Texture

From biological observations it is evident that the aspect of a slope has a strong influence on its microclimate. In a study of emergence from the soil in springtime of the raspberry cane midge, Gunn and Foster (1978) reported that emergence from a South West facing slope was around 14 days earlier than from a North facing slope. Additionally, in a study on maize development (Carr, 1977) mean 5 cm soil temperature differences of up to 3°C were observed between selected "warm" and "cool" sites, while the corresponding air temperature varied by less than 1°C. These differences were not due to aspect alone, but also soil texture, chalk content and shelter.

*Daily plots of estimated soil temperatures, incorporating this equation, against actual temperatures, and an analysis of errors is given in the Annex 2.

Within these constraints the method for calculating soil temperatures proposed here can be modified to account for aspect. If the assumption is made that the daily minimum soil temperature is little affected by aspect, then an increase of the daytime temperature of 2°C well represents the effect caused by a generally southerly slope, with a corresponding decrease for a Northerly slope. (Gordon and Barrie, 1987).

The effects of soil texture and moisture content can, in part at least, be incorporated by applying the equations relating the daily ranges of soil temperature to those of air temperature. A light soil, especially if dry, will experience a greater flux of sensible heat than will a heavier soil, or one with a higher moisture content. However, as an increase in the flux of sensible heat from the soil will be reflected in a larger diurnal variation in air temperature, then the effects due to both soil texture and moisture become partially implicit in the equations like 10 and 11. The regressions against solar radiation alone will not account for this process.

Key words:

Soil temperature; diurnal range; accumulated temperature.

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Met. Unit
MAFF ADAS
Woodthorne
Wolverhampton
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Annex 1 Top Soil Texture at Trial Sites

		Aspect
Luddington EHS	sandy clay loam	flat
Stockbridge House EHS	sandy loam	flat
Arthur Rickwood	peat	flat
Boxworth	clay loam	flat
Bridgetts	silt loam over chalk	SW (?)
Terrington	silty clay	flat

Annex 2

Calculation of Errors

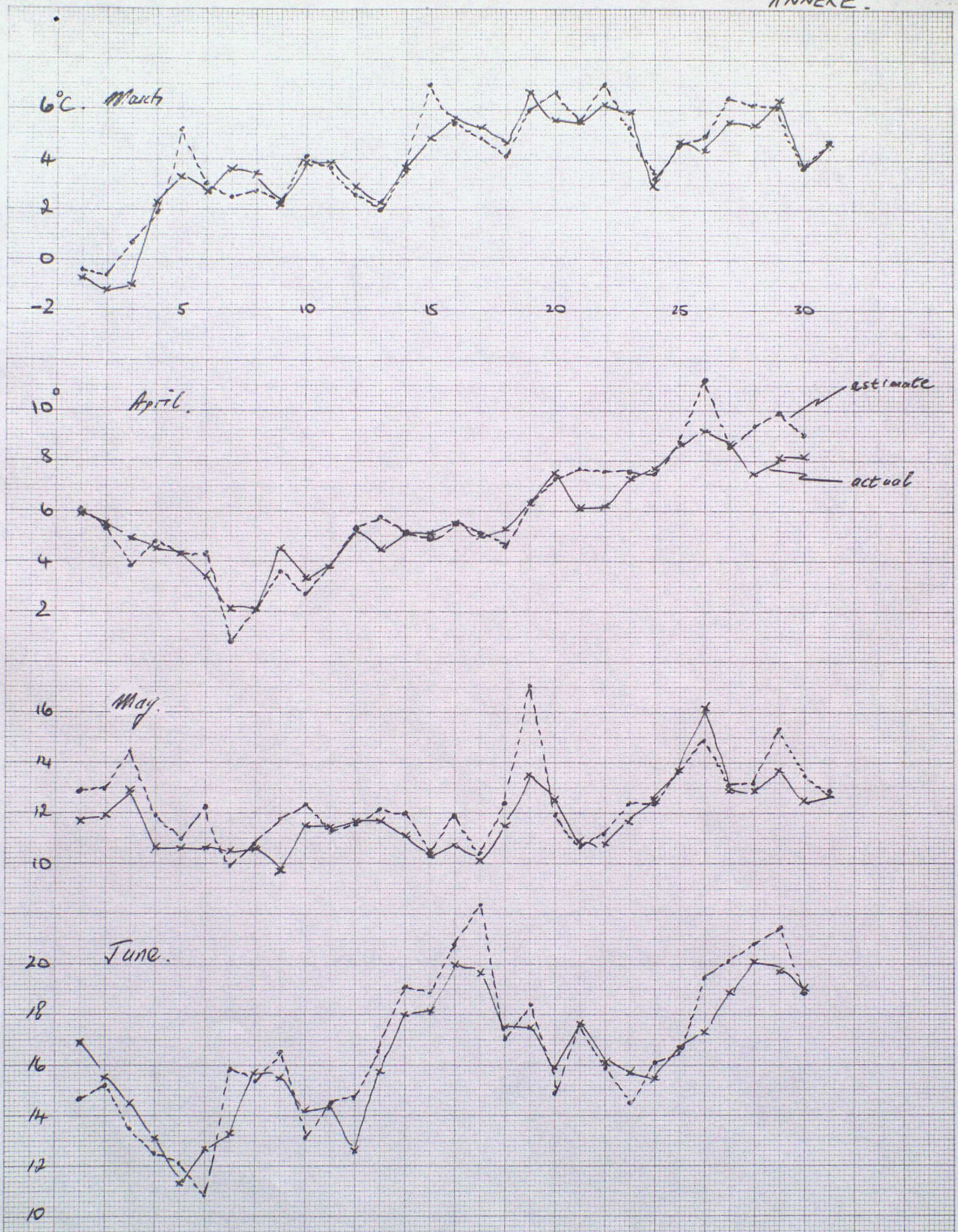
Calculations of the differences between actual and estimated daily mean 10 cm soil temperatures were made on two sets of independent data, Luddington 1985 and Stockbridge House 1986. Both the mean difference and the mean absolute difference (ignoring the direction of the error) are given in the table.

Monthly Differences Between Estimated and Actual Temperatures

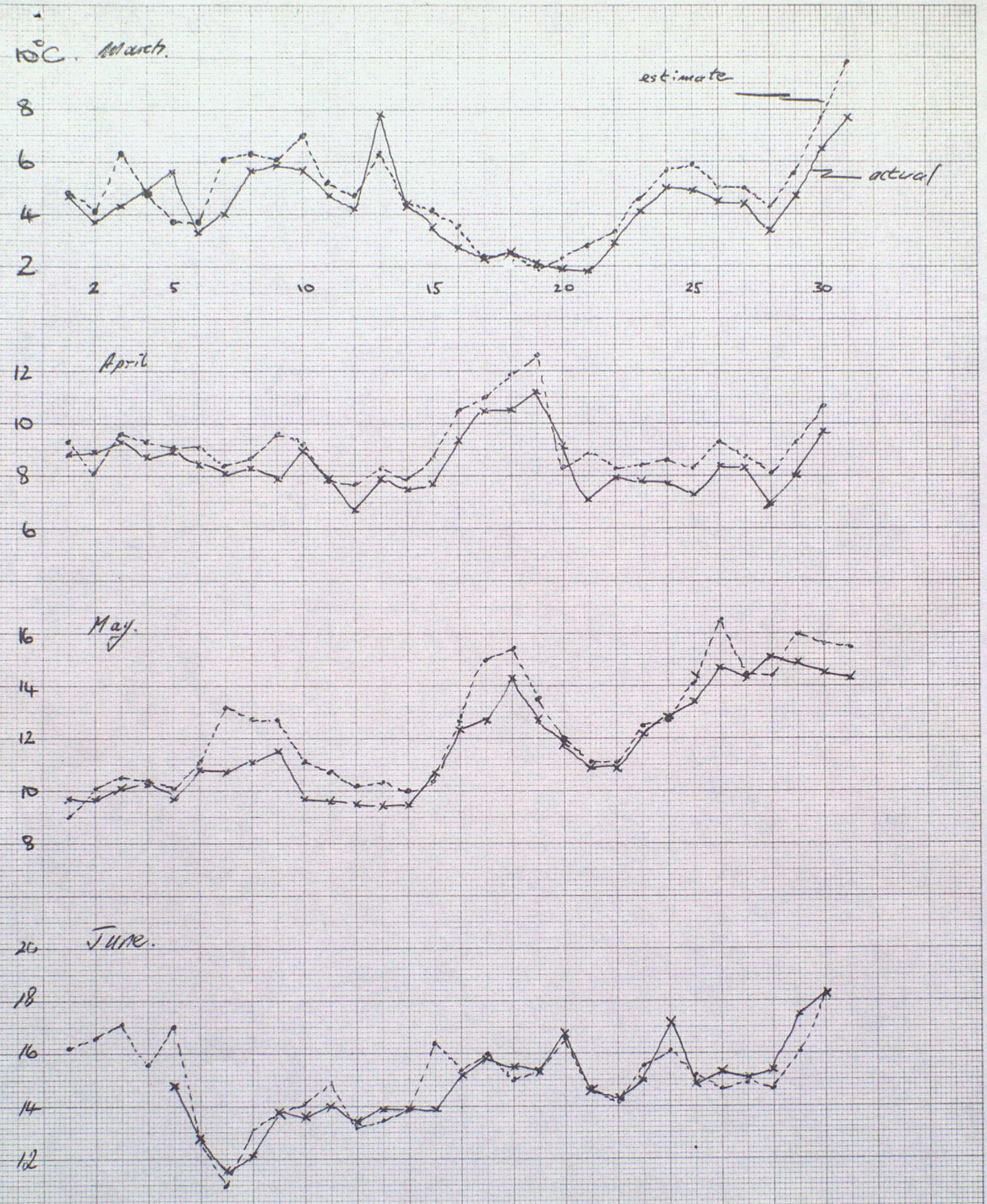
		March	April	May	June
Luddington, 1985	mean abs. error	0.76	0.78	0.74	0.66
	mean error	0.51	0.67	0.62	0.19
Stockbridge, 1986	mean abs. error	0.57	0.60	0.81	1.01
	mean error	0.17	0.23	0.62	0.31

Thus the mean absolute error is normally less than 0.8°C (average of two site years = 0.74°C) and the mean error is 0.55°C (ie an over estimate).

ANNEXE.



Actual vs Estimated 10cm Mean Daily Soil Temperature
Stockbridge House EHS (Cawood), 1986.



Actual vs Estimated 10 cm Mean daily soil temps.
Ludlington EHS 1985.